Chapter 12 CURRENT ELECTRICITY

ELECTROSTATIC: Study of charges at rest.

CURRENT ELECTRICITY: Study of charges at motion.

Electric Current:

⇒ The flow of charges in definite direction is called electric current.

⇒ It is the flow of charges in a unit time.

⇒ Current is represented by $'I'$.

⇒ The current does not depend upon the cross-sectional area. It may be of any type.

⇒ If $'q'$ is charge flowing through a conductor in time $'t'$ then current is given by;

$$Current, I = \frac{q}{t}$$

⇒ As a convention the direction of flow of positive charges is taken as the direction of current flow.

⇒ If moving charges are negative then direction of current is opposite, as in case of metal.

⇒ If the charge moving through a conductor is not steady but varying with time then electric current at any instant of time is given by,

$$Instataneous\ current = \frac{dq}{dt} \quad d \rightarrow represents\ small\ change$$

⇒ ***Mathematically:***

$$I = \frac{q}{t} \Rightarrow \frac{ne}{t}$$

$$n = \frac{It}{e} \quad n \rightarrow no\ of\ electrons, e \rightarrow charge\ one\ 1\ electron$$

⇒ Current has magnitude as well as direction but still it is scalar quantity.

⇒ It is scalar quantity because it does not follow vector law of addition.

⇒ One second reason is that both charge and time are scalar in nature.

⇒ In some books current is called "***Tensor quantity***" (neither scalar not vector)

⇒ The direction of current is due to the flow of charges.

⇒ The direction of current tells us about the effect of charge.

⇒ The cause of current is potential difference.

⇒ In the absence of electric field, the paths of electrons between successive collisions are straight line while in presence of electric field the paths are generally curved.

⇒ The net charge in a current carrying conductor is zero.

⇒ If n particle each having a charge q, pass through a given area in time t then $I = \frac{nq}{t}$.

⇒ If n particles each having a charge q pass per second per unit area, the current associated with cross-sectional area A is $I = nqA$.

⇒ If there are n particle per unit volume each having a charge q and moving with velocity v, the current thorough, cross section A is $I = nqvA$.

⇒ ***Current due to rotatory motion of charge:*** If a point charge q is moving in a circle of radius r with speed v (frequency v, angular speed ω and time period T) then corresponding current

$$I = qv = \frac{q}{T} = \frac{qv}{2\pi r} = \frac{q\omega}{2\pi}$$

⇒ ***Carriers of current;***

I. In Solids (conductor):

- ✓ in conductor there are large number of free electrons, when we applied potential difference the free electrons inside conductor start moving in definite direction, which result current.
- ✓ So, the carrier is current in case of conductor is free electrons.

ii. ***In liquids (Solution of $CuSO_4$ etc):***

- ✓ Both positive and negative ions are current carriers in case of liquids.

iii. ***In gases:***

- ✓ Under ordinary conditions gases are insulators.
- ✓ If gas under low pressure are subjected to high electric field, ionization takes place through which positive and negative ions are produced.
- ✓ Hence in case of gas current carriers are positive and negative ions.

iv. ***In semiconductor:***

- ✓ Both holes and electrons contribute to flow.

SOME IMPORTANT CASES:

$\bar{e} \rightarrow$	$\leftarrow \bar{e}$	In such case $I_{net} = 0$
$- \rightarrow$	$\leftarrow +$	In such case $I_{net} \neq 0$
$+ \rightarrow$	$\leftarrow -$	In such case $I_{net} \neq 0$

⇒ ***Unit of current:***

$$AS\ I = \frac{q}{t} \quad if\ q = 1\ coulomb, and\ t = 1\ sec\ then\ current, I = 1\ ampere$$

Hence unit of Current is ampere.

$$1\ C = charge\ on\ 6.25 \times 10^{18}\ electrons,$$

if we say that current through a wire is 1 A this means that in one second 6.25×10^{18} electrons will flow in 1 sec through any cross section of area.

What is the difference between conventional current and electron current?

Conventional Current - current flows from positive to negative.
Electron Current - current flows from negative to positive.

So, which one is real?

Electron current is the real current. Current is nothing but flow of electrons.
The positive charge is just an atom which is in fixed position and the free electrons only move. That's why we call current as Electric current.

Types of current:

There are three types of current.

i. ***Steady current:*** when a current does not change in magnitude with time.
ii. ***Varying current:*** when a current change in magnitude with passage of time.
iii. ***Alternating current:*** when magnitude of current changes with time but direction is changes periodically.

The main difference between A.C and DC is;
AC Shows heating effect only
DC Shows heating effect, chemical effect and magnetic effect of current

Rectifier convert AC to DC while Inverter Converts DC into AC.

$$AC \rightarrow Rectifier \rightarrow DC$$
$$DC \rightarrow Inverter \rightarrow AC$$

dc flows uniformly throughout the cross-section of conductor while ac mainly flows through the outer surface area of the conductor. This is known as skin effect.

There are several common misconceptions associated with current in a circuit. One is that current comes out of one terminal of the battery and is then "used up" as it passes through the resistor, leaving current in only one part of the circuit. The truth is that the current is the same *everywhere* in the circuit. A related misconception has the current coming out of the resistor being smaller than that going in, because some of the current is "used up." Another misconception has current coming out of both terminals of the battery, in opposite directions, and then "clashing" in the resistor, delivering the energy in this manner.

This is not the case—the charges flow in the same rotational sense at *all* points in the circuit.

"Current Flow" Is Redundant

The phrase current flow is commonly used, although it is strictly incorrect, because current is a flow (of charge). This is similar to the phrase heat transfer, which is also redundant because heat is a transfer (of energy). We will avoid this phrase and speak of flow of charge or charge flow

Current Density (J)

⇒ It is defined as the electric current per unit cross-sectional area at any point.

⇒ Remember that area is normal to the direction of charge flow (or current passes) through that point.

⇒ It is a vector quantity.

⇒ Direction of current density is same as that of $\vec{E}$.

⇒ It is given by;

$$\vec{J} = \frac{I}{A}$$

$$\text{the relationship between } J \text{ and } v_d = J = nev_d$$

Drift velocity:

⇒ The word drift mean push, and velocity means change in displacement in a unit time.

⇒ The average velocity with which free electron get drifted in a metallic conductor under the influence of electric field.

⇒ It is represented by $\vec{v_d}$.

⇒ The drift velocity of electron is in order of $10^{-5}\ ms^{-1}$. Which is very small.

⇒ The drift velocity is responsible for current in metal.

⇒ When a light is turn on, it turns on so quickly, although the drift velocity of electron is small. How? it is because the propagation of electric field takes place with speed of light so electric field is generated due to which the free electrons everywhere in wire begin drifting almost at once. Note that electric field generates everywhere in wire.

⇒ **Different equation of drift velocity;**

$v_d = \frac{i}{neA}$	$v_d = \frac{J}{ne}$	$v_d = \frac{\sigma E}{ne}$	$v_d = \frac{E}{\rho ne}$	$v_d = \frac{V}{\rho lne}$

n = Number of electrons per unit volume of the conductor

A = Area of cross-section

V = potential difference across the conductor

E = electric field inside the conductor

i = current, J = current density, ρ = specific resistance, σ = conductivity

$$\sigma = 1/\rho$$

⇒ The direction of drift velocity for electron in a metal is opposite to that of applied electric field. $v_d \propto E$.

⇒ If diameter (d) of a conductor is changes, then drift velocity of electrons inside it will not change.

Electromotive force (EMF)

⇒ A device that maintain potential difference between two points is said to develop electromotive force.

⇒ It can also be defined as the energy supplied by the cell to driven a unit charge once around the complete circuit.

⇒ The purest voltage of a circuit is called emf.

⇒ The work done in displacing a charge from lower to higher potential inside source is called emf.

⇒ A force which motivates the charge towards respective electrodes.

⇒ A device which convert non-electrical energy into electrical energy.

⇒ Note that emf is called force instead of incorporating the word 'work' into the terminology. However, emf has unit of work and not unit of force.

⇒ You can think of a source of emf as a "charge pump." When an electric potential difference exists between two points, the source moves charges "uphill" from the lower potential to the higher.

⇒ ***Mathematically:***

$$Emf = \frac{work}{charge} = \frac{W}{q}$$

$$as\ V = IR$$

$$\varepsilon = IR \Rightarrow I = \frac{\varepsilon}{R} \Rightarrow I = \frac{\varepsilon}{R+r} \Rightarrow \varepsilon = IR + Ir$$

where r is the internal resistance (will be explained later)

⇒ The Si unit of emf is *volt.*

⇒ The emf of a cell is said to be one volt if 1 joule of energy is supplied by the cell to drive 1 coulomb of charge once around the complete circuit.

⇒ ***Terminal potential:***

Energy per unit charges supplied by source to electrical circuit.
Or it is potential difference at the terminal of battery (+ and – terminal) when connected in circuit.
It is the potential along the electrode when the cell is delivering current or charges.

$$(V_t < E)\ or\ (V_t = E)$$

- When the cell is delivering no current, the terminal potential difference is equal to emf.
- When the resistance R is connected across the cell and current, I flowing along the circuit, this current cause a voltage drop that is equal to (Ir) across internal resistance of the cell soo the terminal voltage V_t is less than the emf of the cell.

$$\therefore I = \frac{E}{R+r} \Rightarrow IR + Ir = E$$

$$and\ IR = V_t = terminaal\ p.d\ of\ the\ cell$$

$$V + Ir = E$$

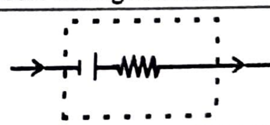
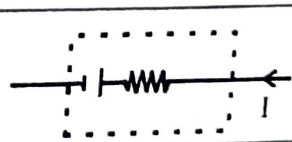
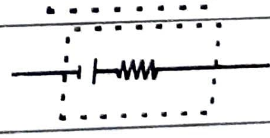
$$\therefore V_t = E - Ir$$

Due to voltage drop in the internal resistance which is equal to (Ir) of the cell the terminal voltage.

⇒ ***Sources of Emf:***

i. Devices that can provide EMF include electrochemical cells, thermoelectric devices, solar cells, electrical generators, transformers, and even Van de Graaff generators.

ii. In nature, EMF is generated whenever magnetic field fluctuations occur through a surface.

i.	When the cell is delivering current to the load (e.g. Resistor) it is said to be discharging. In this case the terminal voltage V of the cell is less than its emf. i.e. $V = E - Ir$	
ii.	During charging of the cell direct current is supplied to the cell from *dc* source. In this case terminal potential difference of the cell is more than its emf. i.e. $V = E + Ir$	
iii.	No current V = E	

What Is Constant In a Battery?

It is a common misconception that a battery is a source of constant current. But this is not true the current in the circuit depends on the resistance connected to the battery. It is also not true that a battery is a source of constant terminal voltage, A battery is a source of constant emf.

Emf Is Independent of the resistance of the circuit and depends upon the nature of electrolyte of the cell while potential difference depends upon the resistance between the two points of the circuit and current flowing through the circuit.

If external load (Resistor) is connected to power supply (emf) source is called loaded circuit.

Internal resistance of a supply

⇒ The resistance offered by the cell to current flow is called internal resistance of cell.
⇒ It is the resistance that is associated with the source.
⇒ It is the resistance of electrolytes of battery.
⇒ The internal resistance (r) is usually low as compared to the external resistance (R).
⇒ It is generally represented by (r).
⇒ The internal resistance can never be zero.
⇒ The internal resistance is zero of ideal source.
⇒ **It depends upon;**

- Distance between the plates. $Internal\ reistance \propto Distance\ between\ the\ plates.$
- Nature of electrolytes used in the source.
- Concentration of the electrolytes. $Internal\ resistance \propto concentrations\ of\ electrolyte$
- Area of plates. $internal\ reistance \propto \frac{1}{area\ of\ plates}$

⇒ **Mathematically:**

$$V_t = E - Ir$$

$$internaal\ resistance\ is\ given\ by; r = \frac{E-V}{I} = (\frac{E-V}{V})R \qquad As\ I = \frac{V}{R}$$

Difference between Emf and Potential difference

	$E.M.F\ (E)$		$Potential\ difference\ (V)$
i.	It is potential difference across the terminal, when it is not delivering current.	i.	It is potential difference across the terminal when it is delivering current.
ii.	It is independent if circuit resistance.	ii.	It depends upon circuit resistance. (V=IR)
iii.	It maintains potential difference.	iii.	Its duty is to maintains current flow.
iv.	$E > V$ because it is purest	iv.	It is less than E
v.	The term is used for Voltage source that convert non-electrical energy into electrical energy.	v.	It is the voltage between two points in a closed circuit.

Ohm's Law

⇒ Ohm's law gives us relationship between voltage and current through a conductor.
⇒ It states that 'the current through conductor is directly proportional to its potential difference across ends'.
⇒ The physical conditions like temperature etc. must not be changes.
⇒ Mathematically;

$$I \propto V \Rightarrow \frac{V}{I} = constant = R$$

⇒ R(Resistance) is constant of proportionality.
⇒ Note that $\frac{V}{I}$ is constant term, as, if V is doubled up, current will also be doubled up so the ratio $\frac{V}{I}$ remains constant.
⇒ The slope of V and I graph gives us Resistance.

$$tan\theta = \frac{V}{I} = R$$

⇒ Ohm's law is not a universal law, those conductors which obeys Ohm's law is called ***ohmic conductors***. For ohmic conductor the V and I graph gives us straight line.
⇒ If material is ***not Ohmic*** e.g. gases, crystal rectifiers, thermionic valve, transistors etc. then the relation between V and I will not be linear, so that R is not constant.
⇒ One most important concept is that $R = V/I$ serves as the definition whether the material is ohmic or not.
⇒ We take V along Y-axis and I along x-axis.

A non ohmic conductor may conduct poorly or not at all when the potential difference is reversed.

Resistance

⇒ It is the opposition offered by the substance to the flow of current.

⇒ Conductor (aluminum, silver, copper) offers very low resistance to the flow of electric current.

⇒ Insulator (mica, glass, rubber) offers too much resistance to the flow of electric current.

⇒ Resistance is given by equation;

$$R = \frac{V}{I} \Rightarrow R \propto \frac{1}{I}$$

⇒ The relation shows that greater the resistance of a conductor smaller will be the current flow, lesser the resistance then more current will flow, if potential difference V is kept constant.

⇒ **Unit:**

$$R = \frac{V}{I} = \frac{1V}{1A} = 1\ ohm$$

$$the\ unit\ of\ resistance\ is\ Ohm$$

⇒ Resistance is represented by Ω (ohm).

⇒ **Resistance depends upon:**

$$Resistance \propto length\ of\ conductor\ or\ wire$$

$$Resistance \propto \frac{1}{Area\ of\ cross\ section}$$

Resistance also depends upon the nature of material

It changes with temperature

So;

$$R \propto \frac{l}{A} \Rightarrow R = \frac{\rho l}{A}$$

$$Now\ as\ Volume = Area \times length \Rightarrow A = \frac{V}{l}$$

Formula of resistance in terms of Diameter, radius, volume

$R = \rho\frac{V}{A^2}$	$R = \rho\frac{V}{(\pi r^2)^2}$	$As\ A = \pi r^2 = \frac{\pi D^2}{4}$ $R = \rho\frac{V(4)^2}{\pi^2 D^4}$ $= \frac{\rho V 16}{\pi^2 D^2}$	$R = \rho\frac{l}{A} \Rightarrow \rho\frac{l}{\pi r^2}$	$R = \rho\frac{l^2}{V}$

$\rho(Rho)$ is a constant of proportionality and is known as specific resistance or resistivity.

⇒ **Specific resistance or Resistivity:**

As;

$$R = \frac{\rho l}{A} \Rightarrow \rho = \frac{RA}{l}$$

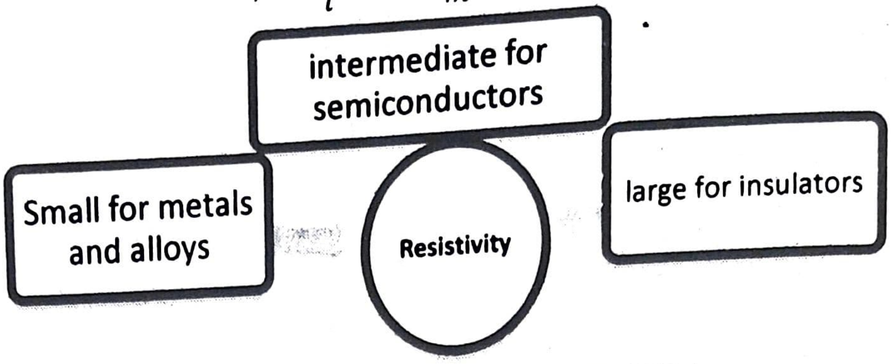
$$if\ A = 1m^2, l = 1m, then\ \rho = R$$

- It is the resistance of unit volume of conductor or wire.
- Resistivity is the resistance between opposite faces of meter cube of a material.
- Resistivity is defined for unit volume.
- Resistivity is the intrinsic property of the substance. It is independent of shape and size of the body (i.e. l and A).
- The value of specific resistance depends upon nature and temperature of material.
- Value of specific resistance is different for different material.
- Resistivity increases with adding impurity.
- Magnetic field increases the resistivity of all metals except iron, cobalt and nickel.
- Resistivity of certain substances like selenium, cadmium, sulphides is inversely proportional to intensity of light falling upon them.

Unit:

As;

$$\rho = \frac{RA}{l} \Rightarrow \frac{ohm \times m^2}{m} \Rightarrow \frac{ohm}{m} \text{ or } ohm\, m^{-1}$$



$Resistivity = Microscopic$
$Resistance = Macroscopic$

Conductance and conductivity (Specific Conductance):

⇒ The reciprocal (opposite) of resistance is called conductance.

⇒ As the conductance is the measure of opposition to the flow of electron, in same sense conductance is the measure of how easily the electrons can flow through a conductor.

⇒ It is represented by $'G'$.

⇒ It is given by;

$$G = \frac{1}{R} \Rightarrow As\ R = \frac{\rho l}{A} \Rightarrow G = \frac{A}{\rho l} \Rightarrow G = \frac{\pi r^2}{\rho l} \Rightarrow G = \frac{\pi D^2}{4\rho l}$$

⇒ **Conductivity (Specific conductance) Because we specified length and area:**

- The reciprocal of resistivity is called conductivity.
- Conductance of a unit area or unit dimension (length, area and volume) is called conductivity.

$$\sigma = \frac{1}{\rho}$$

$$we\ know\ that\ G = \frac{1}{R} = \frac{A}{\rho l} = \sigma \frac{A}{l}$$

- **Unit of Conductance and Conductivity is;**

$$\Omega^{-1} m^{-1}$$
$$ohm^{-1} - m^{-1}$$
$$mho - m^{-1}$$
$$siemen\ m^{-1}$$

$$As\ G = \frac{1}{R} \Rightarrow GR = 1$$

the product of conductance and resistance is equal to unity

On the basis of Conductance and Resistance we have divided materials into 3 groups:

I. Conductors:

- Contain many free electrons. (electrons that are available for flow (electric current))
- High conductivity.
- Metals are good conductors such as; copper, silver and aluminum.
- Large current can flow through conductor by applying small potential difference.

II. Semiconductors:

- Intermediate conductivity.
- Germanium and silicon are example.
- Through a small potential difference small current flow through it.
- Note that; its conductivity can be increased by adding dopants or impurities,

III. Insulators:

- No free electrons.
- Conductivity approaches to zero.
- Non-metals such as, glass, rubber and mica.
- By applying small ΔV no current or negligible current flows through it.

Resistance and Resistivity

Resistivity is property of a substance, while resistance is a property of an object. We have seen similar pairs of variables before.
For example, density is a property of a substance, while mass is a property of an object

Misconception

$$Since\ R = \rho\frac{l}{A} \Rightarrow R \propto l$$

It is incorrect to think that if the length of a resistor is doubled its resistance will become twice.
If you look by an eye of physicist you will find that when l change, A will also change.

Temperature dependence of Resistance:

⇒ It has been found experimentally that in normal temperature range resistance of metal is directly proportional to temperature or show linear relationship. (it increases with temperature)

⇒ Let R_o is the resistance of metallic conductor at $0°C$.

⇒ R be the resistance at $t_1 C°$.

at normal temperature;

- The increase in resistance or difference $(R - R_o)$ is directly proportional to initial resistance.

$$(R - R_o) \propto R_o \quad ...(1)$$

- Is directly proportional to the increase in temperature,

$$(R - R_o) \propto t_1°C \quad ...(2)$$

- $(R - R_o)$ also depends upon the nature of material.

combining equation (1) and (2) we get;

$$R - R_o \propto R_o t_1$$

$$R - R_o = \alpha R_o t_1$$

α is constant of proportionality and is known as temperature co − efficient of resistance.

α is given by;

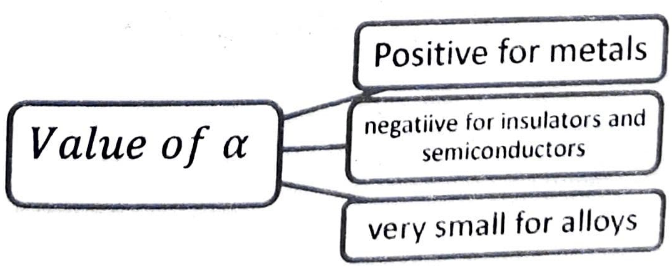
$$\alpha = \frac{R - R_o}{R_o t_1}$$

α is the ratio of change in resistance per unit resistance and temperature.
It is the increase in resistance per ohm original resistance per °C rise in temperature.

a: if $R_{final} > R_{initial} \Rightarrow \Delta R = +ve \Rightarrow so\ \alpha = +ve$
b: if $R_{final} < R_{initial} \Rightarrow \Delta R = -ve \Rightarrow \alpha = -ve$

⇒ **Unit of α:**

$$ohms/ohms/°C$$



⇒ If value of $\alpha = +ve$ this means that $R \propto T$.

⇒ If value of $\alpha = -ve$ this means that $R \propto \frac{1}{T}$

⇒ Value of α is inversely related with initial resistance. $\alpha \propto \frac{1}{R_o}$.

If value of resistance of conductor is R_x at $t_x°C$ and R_y at $t_y°C$ $(t_x < t_y)$ then:

$$R_x = R_y[1 + \alpha(t_x - t_y)]$$

Types of resistor

i. ***Fixed resistors:*** the resistor whose resistance is fixed for some range of temperature.

   a. Carbon resistor

   b. Carbon film resistors

ii. ***Variable resistors:*** the resistor whose resistance changes with change in temperature.

   a. Wire wound resistor (Rheostat)

   b. Thermistor, thermal resistor, sensor

Thermistor

⇒ It is special type of resistor.

⇒ It is also called temperature resistor.

⇒ A device made up of semiconductor material whose resistance changes with change in temperature.

⇒ Thermistors are made up of semiconductor oxides of nickel, cobalt and iron.

⇒ The α (temperature co-efficient) is very high for thermistor.

⇒ *the* α can be both positive and negative for thermistor.

⇒ ***Uses:***

- One most important use is that they can be used continuously without fear of over-heating and appliance damage. A thermistor with negative α is used as a safeguard against current surges in a circuit.
- They are also used to issue an alarm for excessive winding of motors.
  This could be harmful.
  For these types of thermistor $R \propto 1/T$.
- Thermistor are used for measurement of low temperature. If the range is in between 10 kelvins.
- Remote sensor.
- As a voltage stabilizer.
- Temperature control.
- Washing machines, clothes dryers, refrigerators and freezers, hair dryers, curling irons, ovens, toaster, thermostat, air conditioner.

> ✓ Thermistor may be conductor or superconductor.
> ✓ In case of conductor heat up cause resistance.
> ✓ In case of semi-conductor, the heat decreases the resistance because the electron free with heat.

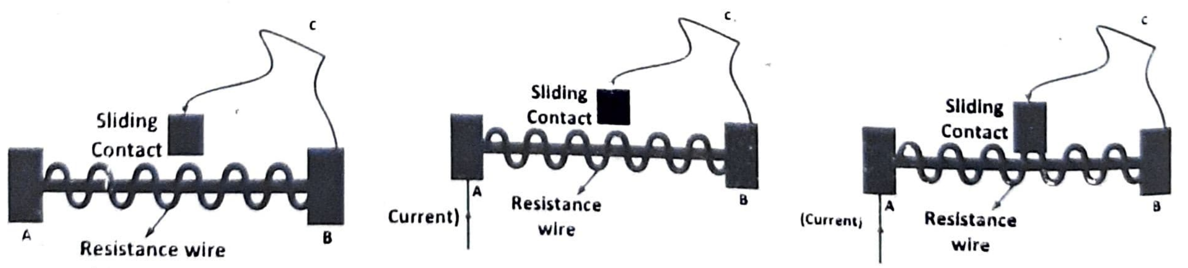
Rheostat and Potential divider

$$Rheostat \Rightarrow Rheo = Stream \quad and\ stat = regulating\ device$$

⇒ Through rheostat we can regulate flow of charge.

⇒ Regulating means change path for flow of charge.

⇒ The construction of Rheostat is given in diagram;



⇒ Initially there are three terminals. And there are no current flowing through circuit.

⇒ If we give current to the circuit (as shown in 2nd figure) then current flows through resistance wire. And total resistance in this case will be 'R' (the resistance if wire only).

⇒ In third case if we touch the sliding contact with resistance wire. (as shown in 3rd figure) now there are two paths for flow of electric current.

Now there are two paths for flow of current.

(i) one is through sliding conatct

(ii) 2nd is through resistance wire

As the resistance wire offered too much resistance to the flow of electric current.

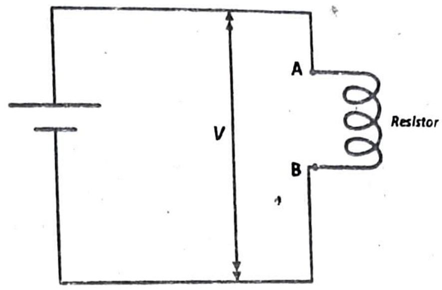
And the path of sliding contact offers little resistance to the flow of electric current.
Simply we can say that the current will move toward 'C' through sliding contact.

⇒ If sliding contact is moving towards point 'A' then the current for resistance will be start decreasing. ***(Rheostat)***

⇒ If sliding contact is moving toward 'B' then the current for resistance will start increasing. ***(Potential divider).***

⇒ ***Construction of potential divider:***

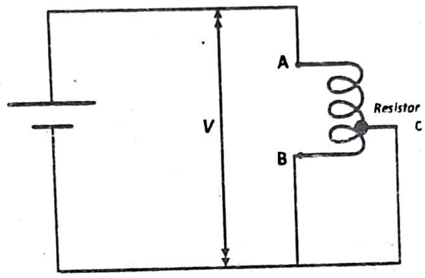
i. In 1st case the potential difference between A and B is given by;



The potential difference A and B will be equal to potential difference of Battery.
The potential drop across A and B is given by;

$$V_{AB} = IR_{AB} \Rightarrow I_{AB} = \frac{V}{R}$$

ii. In 2nd case if we join another contact with resistor, say 'C'



Now in this case again there are two paths for current flow.
Again, we will neglect the current flow through wire 'C' from the point of contact.
Now potential drop between 'B' and 'C' will be;

$$V_{BC} = I \times Resistance \Rightarrow \frac{V}{R_{AB}} \times r_{BC} \Rightarrow V_{BC} = \frac{V_r}{R}$$

✓ *As the wire C is moved toward point 'A' then the resistance (r) will be start increasing as a result the output potential will be greater.*

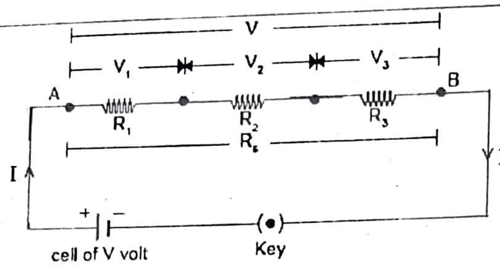
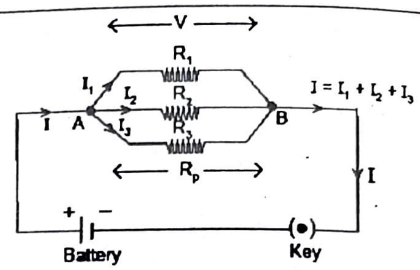
✓ *If we move the wire 'C' towards point 'B' then then current will pass through total resistance (R) in this case there will be more opposition for flow of charges. And output voltage will be minimum.*

With the help of potential divider, we can vary potential between maximum and minimum, that's why it is so called ***potential divider***.

You may have heard a phrase like "current takes the path of least resistance" in reference to a parallel combination of current paths, such that there are two or more paths for the current to take. The phrase is incorrect. The current takes all paths. Those paths with lower resistance will have large currents, but even very high-resistance paths will carry some of the current.

Characteristics of Combination of Resistors

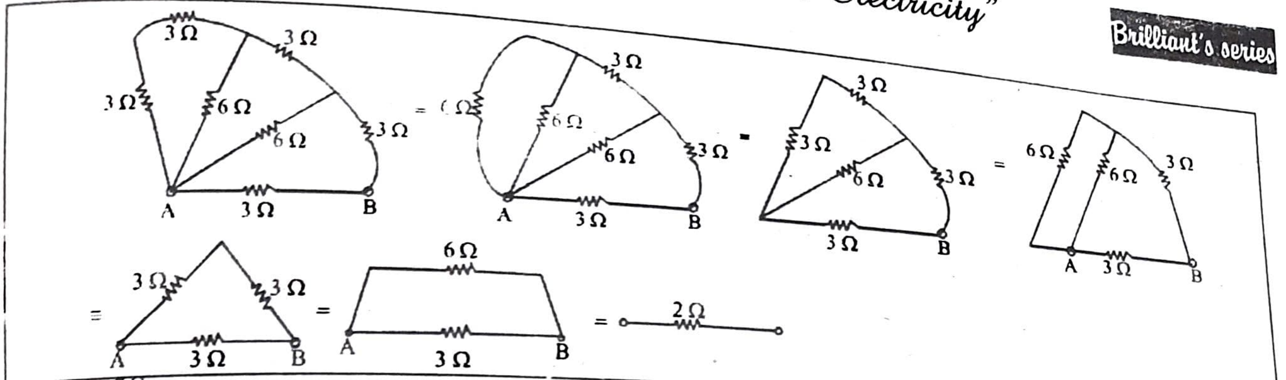
Series combination	Parallel combination

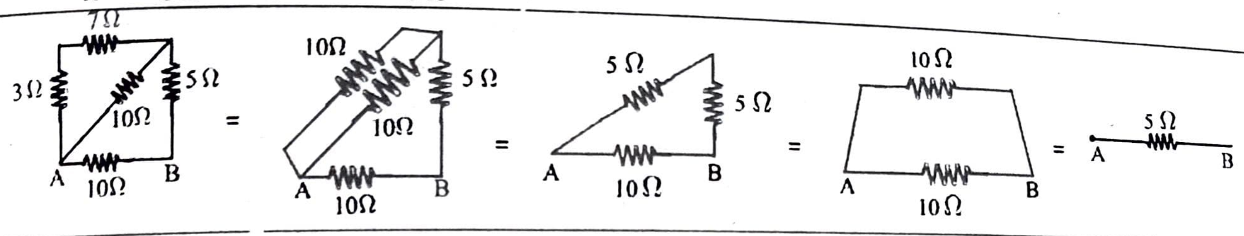
Series	Parallel
	
✓ When the resistors are connected in such a way that the total resistance is equal to the sum of individual resistances. Let, R_1, R_2, R_3 be three resistors when they are connected in series equivalent resistance is given by; $R_{eq} = R_1 + R_2 + R_3$	✓ When a number of resistors are connected in such a way that the reciprocal of resistance is equal to the sum of reciprocal of individual resistances. Let R_1, R_2, R_3 be three resistors when they are connected in parallel equivalent resistance is given by; $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
✓ $V_1 = IR_1, V_2 = IR_2, V_3 = IR_3$	✓ $I_1 = \frac{E}{R_1}, I_2 = \frac{E}{R_2}, I_3 = \frac{E}{R_3}$
✓ $E = V_1 + V_2 + V_3$	✓ $I = I_1 + I_2 + I_3$
✓ $E = IR_1 + IR_2 + IR_3$	✓ $I = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3}$
✓ $E = I(R_1 + R_2 + R_3)$	✓ $I = E\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) \Rightarrow \frac{I}{E} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$
✓ The total current across total resistors in series is given by; $I = \frac{E}{R_{series}}$	✓ Note that $\frac{E}{I} = R_{parallel}$ $\frac{I}{E} = \frac{1}{R_{parallel}}$
✓ If n identical resistance is connected in series $R = nR$ and potential difference across each resistance $V' = \frac{V}{n}$.	✓ In n identical resistance is connected in parallel $R_{eq} = \frac{R}{n}$ and current through each resistance $I' = \frac{I}{n}$.
✓ The current in each resistor is same.	✓ The voltage across each resistor is same.
✓ The total resistance across circuit is equal to the sum of individual resistance. (internal + External)	✓ $I \propto \frac{V}{R}$
✓ The voltage drop across any resistor is directly proportional to resistance of the circuit.	✓ The total current in the circuit is equal to the sum of current in its parallel branches.
✓ The current in the circuit is independent of relative positions of the resistors.	✓ As the number of parallel branches is increased the total resistance of circuit is decreased.
✓ The total resistance in the series circuit is more than the largest resistor in the circuit.	✓ The total resistance in the circuit is less than the smallest resistor.
✓ If one resistor is series fails the current in the whole circuit ceases. It is the main disadvantage of series circuit.	✓ There is no effect of one resistor on another, so if, current through any one resistor in parallel circuit falls the current in circuit along other resistors will still flow. That's why parallel circuits are preferred more as compared to series circuit.

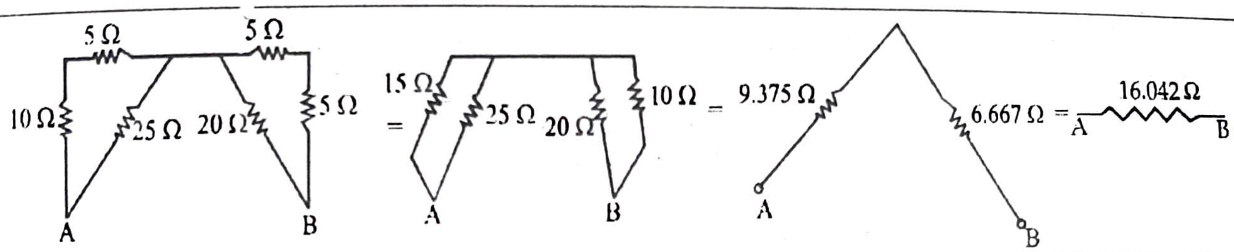
HOW TO FIND EQUIVALENT RESISTANCE?

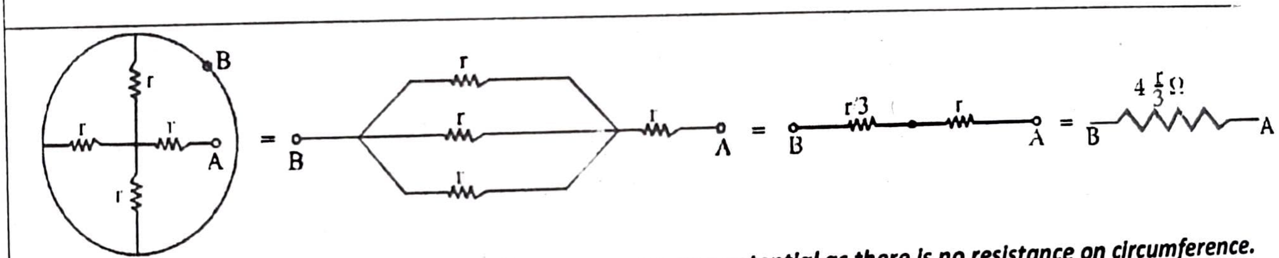
Successive Reduction

This method is applicable only when the resistors can be clearly identified as in series or parallel. Let us take some example to find resistance between ends A and B





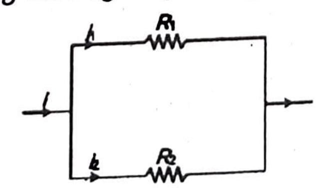




Please note that all points on the circumference are at same potential as there is no resistance on circumference.

important cases of finding Resistance and current in a parallel Resistance circuit

if two resistors are connected in a circuit in parallel and the current I divides into two parts I_1 flowing through R_1 and I_2 flowing through R_2



Then Equivalent resistance is given by;

$$\frac{1}{R_{equivalant}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_2 + R_1}{R_1 R_2} \quad OR \quad R_{equivalant} = \frac{R_1 R_2}{R_1 + R_2} = \frac{Product}{Sum}$$

Branch currents;

$$E = IR_p = I\frac{R_1 R_2}{R_1 + R_2}$$

Current through first resistor;

$$I_1 = \frac{E}{R_1} = \left(I\frac{R_1 R_2}{R_1 + R_2}\right)\frac{1}{R_1} = I \times \frac{R_2}{R_1 + R_2}$$

Current through 2nd resistor;

$$I_2 = I \times \frac{R_1}{R_1 + R_2}$$

Current in any of two branches;

$$Current\ in\ any\ branch = Total\ current \times \frac{Another\ resistance}{sum\ of\ two\ resistances}$$

Some Other important points:

- ✓ Resistivity of a material is inversely proportional to the number of free electrons per unit volume.
- ✓ If a conducting wire stretches, it's length increases, area of cross-section decreases so resistance increases but volume remain constant.
  If R_1 *be the resistance before streching and* R_2 *be the resistance after streching then the ratio of its length, area radius and diameter is given by;*

$$\frac{R_1}{R_2} = \frac{l_1}{l_2} \times \frac{A_2}{A_1} = \left(\frac{l_1}{l_2}\right)^2 = \left(\frac{A_2}{A_1}\right)^2 = \left(\frac{r_2}{r_1}\right)^4 = \left(\frac{d_2}{d_1}\right)^4$$

- ✓ If we stretch or compress wire its resistivity remains constant.
- ✓ ***If we compress the wire then;***

$$new\ length = \frac{original\ length}{no\ of\ times\ compressed}$$

$$new\ Area = original\ area \times no\ of\ times\ compressed$$

$$New\ resistance = \frac{Initial\ resistance}{n^2}$$

- ✓ ***If we stretch the wire then:***

$$new\ length = original\ length \times no\ of\ times\ stretched$$

$$new\ area = \frac{n}{A}$$

$$R' = n^2 R$$

- ✓ After stretching if length of a conductor increases by x% then resistance will increases by 2x % (valid only if x < 10%).
- ✓ Using n conductors of equal resistance, the number of possible combinations is 2n – 1.
- ✓ If the resistance of n conductors is totally different, then the number of possible combinations will be 2n.
- ✓ If n identical resistances are first connected in series and then in parallel, the ratio of the equivalent resistance is given by $\frac{R_P}{R_S} = \frac{n^2}{1}$.
- ✓ If a wire of resistance R, cut in n equal parts and then these parts are collected to form a bundle then equivalent resistance of combination will be R/n^2.
- ✓ If equivalent resistance of R_1 *and* R_2 in series and parallel be R_{series} *and* $R_{parallel}$ respectively then

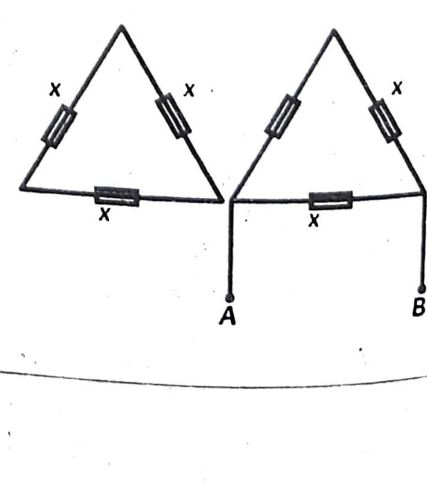
$$R_1 = \frac{1}{2}\left[R_s + \sqrt{R_s^2 - 4R_sR_p}\right]\ and\ R_2 = \frac{1}{2}\left[R_s - \sqrt{R_s^2 - 4R_sR_p}\right]$$

- ✓ If wire of resistance R are connected in such a way that they form an angle of 60° (Triangle) with each other A and B will be;
  As;

$$R = \frac{\rho l}{A},\ here\ x + x + x = l, so\ x = \frac{l}{3}$$

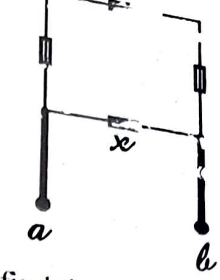
$$the\ resistance\ of\ each\ sides\ will\ be\ \frac{R}{3}.$$

The upper 2 sides are in series and the lower plane side is parallel to them. Hence simplified.



- ✓ If a wire of resistance 'R' is connected in the form of a square; then;

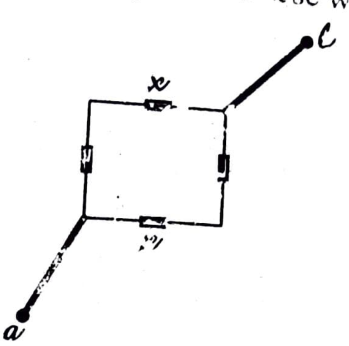




$$x + x + \dots + x = l$$
$$x = l/4$$

Then the resistance of each side is $\frac{l}{4}$. Now we can easily find the resistance between a and b. by series and parallel distribution which you already know.

✓ You may be asked, the resistance between A and B in this case will be;

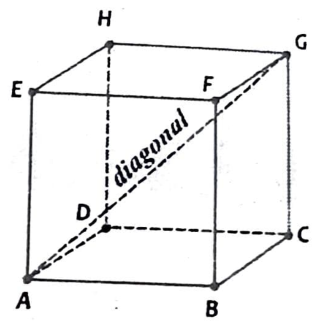


✓ If a skeleton cube is made with 12 equal resistance each having resistance R then the net resistance across;

$$The\ longest\ diagonal\ (EC\ or\ AG) = \frac{5}{6}R$$

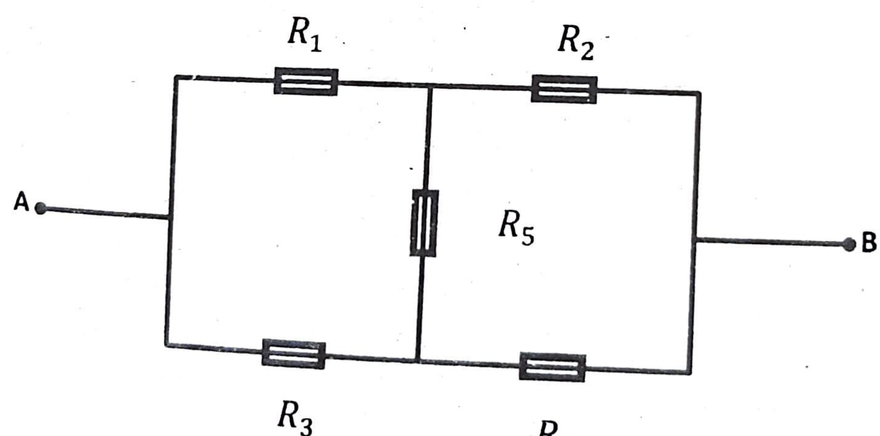
$$The\ diagonal\ of\ face\ (e.g. AC, ED, \dots.) = \frac{3}{4}R$$

$$A\ side\ (e.g. AB, BC \dots..) = \frac{7}{12}R$$



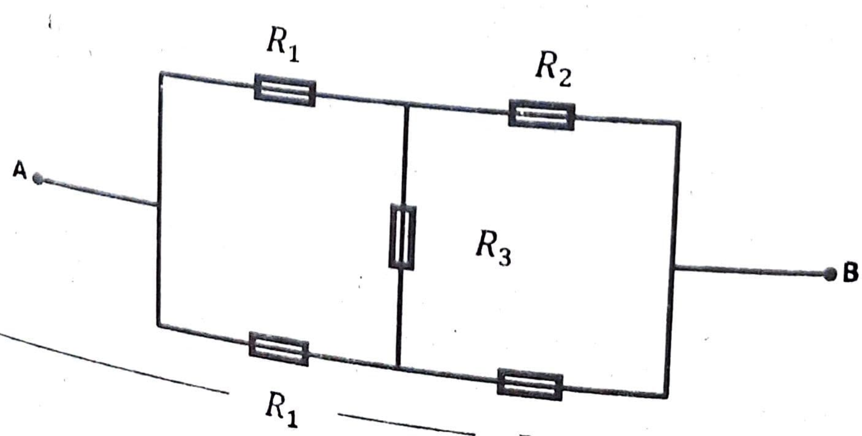
✓ Equivalent resistance between A and B, below picture formula is given;

1)



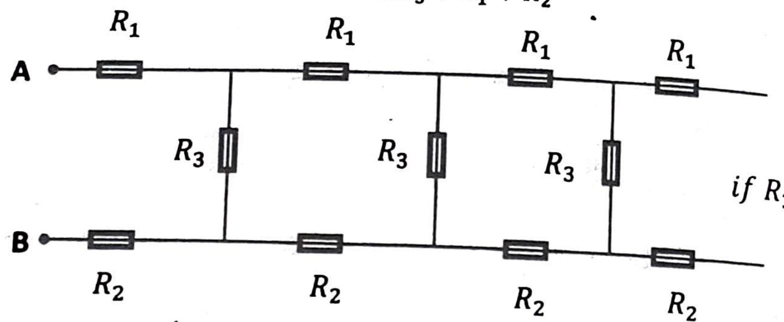
$$R_{AB} = \frac{R_1R_2(R_3 + R_4) + (R_1 + R_2)R_3R_4 + R_5(R_1 + R_2)(R_3 + R_4)}{R_5(R_1 + R_2 + R_3 + R_4) + (R_1 + R_3)(R_2 + R_4)}$$

2)



$$R_{AB} = \frac{2R_1R_2 + R_3(R_1 + R_2)}{2R_3 + R_1 + R_2}$$

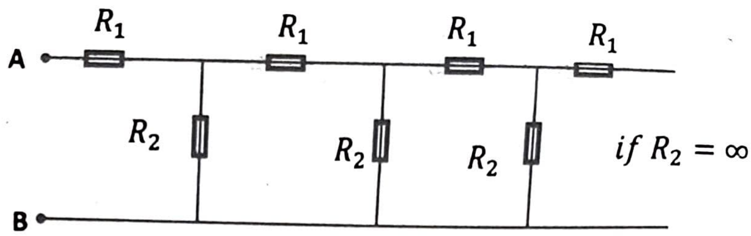
3)



$if\ R_3 = \infty$

$$R_{AB} = \frac{1}{2}(R_1 + R_2) + \frac{1}{2}\left[(R_1 + R_2)^2 + 4R_3(R_1 + R_2)\right]^{\frac{1}{2}}$$

4)

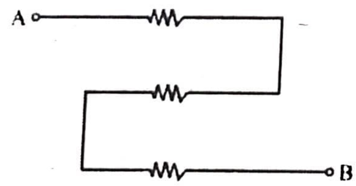


$if\ R_2 = \infty$

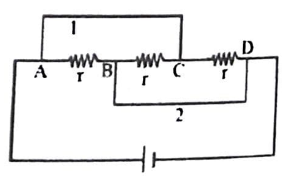
$$R_{AB} = \frac{1}{2}R_1\ 1 + \sqrt{1 + 4\left(\frac{R_2}{R_1}\right)}$$

Misconception

- Incorrect: If two resistances are not in series then it is in parallel and vice-versa.
  Correct: The above thinking is incorrect. We may have resistances which are neither in series nor in parallel.
- Resistors are not just in series or in parallel if they look so geometrically, e.g. the resistors in the diagram are not in parallel but in series



- Incorrect If the current flows in a wire, there has to be a potential difference. The potential drop takes place only when current passes through a resistor.
  Correct: In the diagram, the three resistors are in parallel. The potential at A is equal to the potential at C. Current flows in wire 1 but there is no potential drop across A and C.



- Incorrect: If potential difference between the points is zero, there is zero current between the two points.
  Cooreet: There is no p.d. between A and C still current flows in segment 1.

Electrical power

⇒ The rate at which electric work is done by the voltage source in maintaining electric current in the circuit is called electric work.

⇒ As $I = \frac{q}{t} \Rightarrow q = It$

⇒ if charge 'q' moves through any two points having resistor, it losses electric potential energy, which is given by (qV). In other words, electric work is done in the circuit for t seconds is;

Electric power, $P = \frac{W}{t} = \frac{VIt}{t} = Vt$

Different equations for electric power

$P = VI$	$P = I^2R$	$P = \frac{V^2}{R}$

⇒ **Unit:**

$$\frac{Joule}{second} = watt$$

$$iff\ V = 1\ volt, and\ I = 1A, then\ P = 1 \times 1 = 1watt$$

The bigger units are kilowatt (kW) and megawatt (MW).

The commercial unit of electric power is horse power (H.P). where 1 H.P = 746 W

⇒ Electric appliances are rated in terms of electric power.

⇒ The greater ability of electric appliance to convert electrical energy into other form of energy, then greater the electric power it has.

Power output or power delievered or power of source:

The product of current with voltage of source is called power output.

$$P = VI$$

Power dissipated or Power consumption:

The product of current passing through Resistor (electric appliance) and potential drop through it will be equal to power dissipated.

$$P = I^2R = \frac{V^2}{R}$$

Ratio is;

$$\frac{P_1}{P_2} = \frac{R_2}{R_1}$$

Power output of battery is given by;

$$P_{output} = \varepsilon^2 \left|\frac{R}{(R+r)^2}\right|$$

$$P = \frac{V^2}{R}$$

Electric devices are mostly manufactured on the basis of this equation.

Combination of bulbs;

Series Comination	Parallel comination
If several bulbs are connected in series then it is said to be series combination of bulbs.	If several bulbs are connected in parallel then it is said to be parallel combination of bulbs.
$Total\ power\ consumed = \frac{1}{P_{total}} = \frac{1}{P_1} + \frac{1}{P_2} + \cdots$	$Total\ power\ consumed = P_{total} = P_1 + P_2 + \cdots$
$P_{consumed}(Brightness) \propto V \propto R \propto \frac{1}{P_{rated}}$ i.e. in series combination bulb of lesser wattage will give more bright light and p.d. appeared across it will be more.	$P_{consumed}(Brightness) \propto P_R \propto I \propto \frac{1}{Resistance}$ i.e. in parallel combination, bulb of greater wattage will give more bright light and more current will pass through it.
$if\ n\ identical\ bulbs\ are\ connected = \frac{Power}{n}$	$if\ n\ identical\ bulbs\ are\ connected = n \times Power$

Tips and Tricks:

⇒ The brightness of an electric bulb is directly proportional to the rate of production of heat by bulb.

⇒ When two bulbs of different wattage but of the same rated voltage V is connected in series across 2V then bulb of smaller wattage will fuse.

⇒ In series combination of electric bulb, the brightness of 60W bulb will be more than that of 100W bulb.

$$Resistance \propto \frac{1}{Watt\ of\ Bulb}$$

⇒ $Thickness\ of\ filament \propto Watt\ of\ Bulb$

⇒ The brightness of an electric bulb is directly proportional to the rate of production of heat by bulb.

$$Brightness \propto Watt\ of\ bulb$$

⇒ In house electric appliances are connected in parallel.

⇒ The maximum current that can be safely passed through an appliance (a resistor) is $I = \frac{P_{rated}}{V_{rated}}$.

⇒ Bulbs get fused sometimes when switched on. This is because with the rise in temperature the resistance increases and power decreases $P = V^2/R$ Therefore the bulb glows brighter in the beginning and get fused.

⇒ If I be the current at which a fuse wire of radius R blows, then $\frac{I^2}{R^3}$ constant i.e for two fuse wires of radii R1and R2 and maximum bearing current I1, and I2, we have

$$\frac{I_1^2}{R_1^3} = \frac{I_2^2}{R_2^3}$$

Electrical energy

⇒ The total energy supplied (total work done) by a voltage source in maintaining current in an electric circuit for a given time is called electrical energy.

⇒ The price of electricity consumed is calculated on the basis of electrical energy and not on the basis of electrical power.

⇒ ***It is given by;***

$$Electrical\ energy = VIt$$

Different equations of electrical energy

$E = VIt$	$E = I^2Rt$	$\frac{V^2}{R}t$

⇒ ***Unit:***

$$As\ VI = power = watt, and\ t = time = second$$

$$so\ watt \times second$$

✓ The unit of electrical energy is watt-second or joule.

✓ If power = 1kW and time = 1second, then Energy = 1 W-s or 1 joule.

✓ Note that the commercial unit of electrical energy is kilowatt-hour (kW).

✓ $Electrical\ energy\ in\ kWh = power\ in\ kW \times Time\ in\ hours$

✓ 1 kWh is also called Board of trade unit (B.O.T.U) or simply unit of electricity.

✓ Note that utility bills of PESCO, are made on the basis of total electrical energy consumed by the customer or consumer.

✓ 1 kWh is equal to 1 unit.

✓ If we say that a consumer has consumed 10 kWh energy this means that he has consumed 10 units.

✓ ***Relationship between 1 kWh and joule is;***

$$1\ kWh = 3.6 \times 10^6 J\ or\ 1\ joule = \frac{1}{3.6 \times 10^6}\ kWh$$

Formula to Calculate number of consumed units;

$$No\ of\ conusmed\ units = \frac{Total\ watts \times Total\ hours}{1000}$$

Power output

We know that power output is given by:

$$P_{output} = \varepsilon^2 \left|\frac{R}{(R+r)^2}\right|$$

Maximum power transfer;

... load resistance is made equal to internal resistance of source, in this case there will be maximum power will be transferred from source to load.

✓ By decreasing Resistance of the load up-to internal resistance.

$$P_{output} = \varepsilon^2 \left|\frac{R}{(R+r)^2}\right|$$

As for power output Total Resistance, $R_t = (R+r)$

By taking $r = constant\ R \propto R_t$*, when* R_t *decrease then R will also decrease*

During this Current flow will increase, because $I \propto \frac{1}{R}$

So, in given equation if $r = R$ then:

$$P_{output} = \varepsilon^2 \left|\frac{R}{(R+r)^2}\right| \Rightarrow P_{maximum} = \frac{\varepsilon^2 R}{(R+R)^2} = \frac{\varepsilon^2}{4R}$$

Minimum power transfer;

✓ When r becomes greater than R at that time minimum power will be transferred.

$$P_{output} = \varepsilon^2 \left|\frac{R}{(R+r)^2}\right|$$

As for power output Total Resistance, $R_t = (R+r)$

By taking $R = constant\ R \propto R_t$*, when r increases then* R_{total} *will also increases*

During this Current flow will decrease, because $I \propto \frac{1}{R}$

So, in given equation if $R = r$ then:

$$P_{output} = \varepsilon^2 \left|\frac{R}{(R+r)^2}\right| \Rightarrow P_{minimum} = \frac{\varepsilon^2 r}{(r+r)^2} = \frac{\varepsilon^2}{4r}$$

Hence, we can say that;

$$Minimum\ Power \leq Power\ of\ source \leq Maximum\ Power$$

MISCONCEPTION

It is a common misconception that "current in the circuit will be maximum when power consumed by the load is maximum.

✓ As we know that current I is equal to:

$$I = \frac{E}{(R+r)}$$

Now current will be maximum if the same equation is like;

$$I = \frac{E}{r}$$

Or simply current will be maximum if $R = 0$

✓ Power will be maximum if $R = r$.

Trick: ***If a heating coil of resistance R, (length l) consumed power P, when voltage V is applied to it then by keeping V Constant.***

<u>if it is cut in n equal parts</u>

✓ Then resistance of each part will be $\frac{R}{n}$

✓ And from $P_{consumed} \propto \frac{1}{R}$ power consumed by each part $P' = np$

Heating effect of electric current

○ Joule was first to study heating effect of current inside conductor.

⇒ The passing of electric current through a conductor produces heat, this is called heating effect of current.

⇒ In case of heater, an electric current is passed through a high resistance (heating element) through which the element becomes red hot, heat is produced, thus electrical energy is converted into heat energy.

⇒ ***Cause of heating effect of electric current:***

When we applied potential difference in a conductor, then current start flowing, this current is a result of motion of free electrons inside conductor. At same time these free electrons collide with positron. Positive charges or holes inside conductor through which the kinetic energy of positive ions start increasing, as kinetic energy varies directly with temperature, therefore temperature start rising, which produce heat.

⇒ ***The relation for heating effect of current given by joule is;***

$$H = I^2 Rt$$

This equation is known as 'Joule heating law'.
According to given equation

$$Heat \propto I^2 \text{ (Currrent flowing through conductor)}$$
$$Heat \propto Resistance \text{ (Resistor through which current I passing)}$$
$$Heat \propto \text{time of exposure to current}$$

As;

$$H = VIt = I^2Rt = \frac{V^2}{R}t \text{ joules} = \frac{VIt}{4.18} = \frac{I^2Rt}{4.18} = \frac{V^2t}{R \times 4.18} \text{ calories}$$
$$\text{the value of 1 calorie} = 4.18\,J \text{ is found experimentally}$$

Tricks

⇒ If the two resistors R1and R2 are first connected in series and then parallel then the ratio of heat produced in the two cases (series to parallel) is given by

$$\frac{H_s}{H_p} = \frac{(R_1 + R_2)^2}{R_1 R_2}$$

⇒ If two resistances R1 and R2 are connected in parallel and a current is passed in them such that heat produced in them is H1 and H2 respectively, then

$$\frac{H_1}{H_2} = \frac{R_2}{R_1}$$

Thermocouple

⇒ Thermo stands for temperature, and couple = any two things join together.
⇒ It is pair of conductors which convert thermal energy to electrical energy.
⇒ The cause of this conversion is potential difference.
⇒ For formation of thermocouple two conductors will be of different nature.
⇒ 1 conductor will be kept at higher temperature.
⇒ 2nd conductor will be kept at lower temperature.
⇒ The temperature difference is cause of production of emf like in thermocouples, this is called ***SEEBACK effect,*** because see back was 1st to observe this.
⇒ ***SEEBAACK*** is reversible effect.
⇒ At 1st when the temperature increase there will increase in emf, when temperature is further increase there will start decrease in emf production. After that a temperature will reach on which the emf produced will be equal to = 0.
⇒ Emf produced through thermocouple is called thermo emf.

- ***Neutral temperature:*** the temperature at which thermo-emf is maximum.
- ***Inversion temperature:*** the temperature at which thermo-emf is zero.

⇒ Emf produced by thermocouple is given by;

$$emf = \alpha T + \frac{1}{2}BT^2$$

Thermo couple can be compared to a heat engine. It absorbs heat at the junction (source) converts heat into electric energy (which appears as the circulating electric current) and rejects the remaining heat to cold junction (Sink).

Resistor temperature detector or Resistance thermometer

⇒ Device which measure temperature is called thermometer.

⇒ Resistance thermometer are special type of thermometer made up of resistors which can measure temperature difference.

⇒ They are very sensitive to heat or temperature change.

⇒ They are widely used in electrical circuit and other appliances.

Complex circuit;

⇒ Those circuit having such type of combination of resistors which cannot be solved through ohm's law.

⇒ Those circuit in which resistors are neither in series not in parallel or cannot be solved through series and parallel concept.

Kirchhoff's Law;

⇒ To solve complex circuit Kirchhoff gives two laws;

i. Kirchhoff's junction rule or Kirchhoff's current law

ii. Kirchhoff's loop rule or Kirchhoff's voltage law

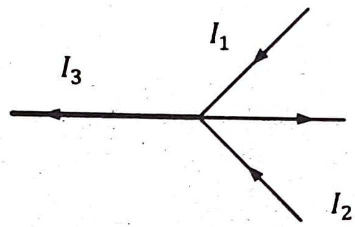
Kirchhoff's Current Law:

⇒ It is also known as junction rule.

⇒ A junction is the point in circuit where three or more circuit elements meet.

⇒ This law is based on conservation of charges.

⇒ ***Statement;*** 'The algebraic sum of current meeting in a junction is equal to zero'.



$$I_1 + I_2 = I_3 + I_4$$

⇒. Sum of incoming current = sum of outgoing current

⇒ According to this law current cannot accumulate at any point in the circuit.

Kirchhoff's Voltage law:

⇒ This law is also known as loop rule or voltage law.

⇒ A close circuit is called loop.

⇒ Statement: the algebraic sum of the changes in potential in complete traversal of a mesh (closed loop) is zero.

⇒ *Algebric sum of e.m.f s + algebric sum of voltage drop* = 0

⇒ This law represents "conservation of energy".

⇒ If there are n meshes in a circuit, the number of independent equations in accordance with loop rule will be (n – 1).

Sign conventions:

✓ In solving problems through Kirchhoff's law, algebraic sum is considered.

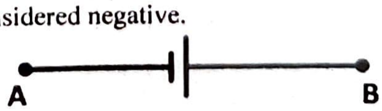
✓ In algebraic sum we consider sign conventions so;
It is very important to assign proper signs to emf and voltage drop in the close circuit.

✓ Charge entering is taken as positive.

✓ Charge leaving is taken as negative.

✓ The following sign conventions may be followed;

1) A rise in potential should be considered positive.
2) A fall in potential should be considered negative.



In given figure if we move from A towards B there will be rise in potential.
If we move from B to A there will fall in potential.

Steps to Solve problems through Kirchhoff's Rule

1) Draw a circuit diagram, and label all the known and unknown quantities. You must assign a direction to the current in each branch of the circuit. Although the assignment of current directions is arbitrary, you must adhere rigorously to the assigned directions when applying Kirchhoff's rules.
2) Apply the junction rule to any junctions in the circuit that provide new relationships among the various currents.
3) Apply the loop rule to as many loops in the circuit as are needed to solve for the unknowns. To apply this rule, you must correctly identify the potential difference as you imagine crossing each element while traversing the closed loop (either clockwise or counterclockwise). Watch out for errors in sign!
4) Solve the equations simultaneously for the unknown quantities. Do not be alarmed if a current turns out to be negative; its magnitude will be correct and the direction is opposite to that which you assigned.

Wheatstone Bridge

⇒ It is a circuit used to determine resistance of unknown resistor in accurate way.

⇒ Wheatstone bridge principle states that when the bridge is balanced then product of resistances of opposite arms are equal.

$$R_1 R_x = R_2 R_3$$

⇒ Note that the value of P and Q are fixed and known.

⇒ The R_2 is variable resistor.

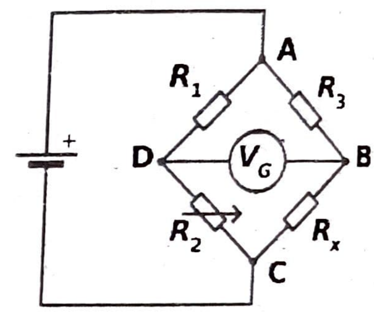
⇒ The value of R_x is unknown.

⇒ Null point is the point at which galvanometer shows zero deflection.

⇒ When no current flow through the bridge then it is said to be balanced.

⇒ At null point we can measure resistance of unknown resistor.

⇒ ***Mathematically the unknown resistance is given by;***



$$\frac{R_2}{R_1} = \frac{R_x}{R_3} \Rightarrow R_x = \frac{R_2}{R_1}.R_3$$

In a Wheatstone bridge, the deflection in a galvanometer does not change, if the battery and the galvanometer are interchanged

Potentiometer

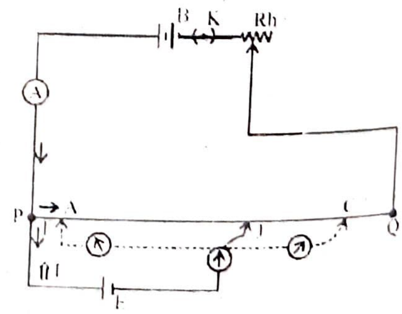
⇒ It is a device used to measure emf of a voltage source accurately.

⇒ It can measure the potential difference between two points.

⇒ The main advantage of this device is that this device measures the potential difference between two points without drawing current.

⇒ ***Some application of potentiometer is;***

1) Compare the emf od two cells.
2) Measure the emf od cells.
3) Compare two resistances.
4) Measure current in a circuit.
5) Measure the internal resistance



⇒ This device is composed of:

1) Long uniform wire of 1 m.
2) Graduated scale that runs parallel to wire.
3) Battery
4) Rheostat and key

⇒ Working:

PQ is the resistance wire of potentiometer generally made up of constantan or nichrome. One end P is connected to the positive terminal of the battery B while negative terminal is connected to Q through a Rheostat (Rh) and key (K). This is the main circuit.

A cell whose emf has to be measured is also connected to the potential wire in such a way that the positive terminal is connected with P and negative terminal is connected to a galvanometer and then to a jockey (J) which is free to slide along the wire.

There is a potential drop along PQ.

The potential drop per unit length along PQ is called potential gradient.

When the jockey is pressed on some point, current flows from E to P (⇒). Also current that comes from B after reaching P divides into two parts. One part moves towards A and the other towards E (→).

Three cases may arise.

i.	$I_B > I_E$ **This happens when VPC > E. One side deflection in galvanometer**
ii.	$I_B = I_E$ **This happens when VPC = E, Zero deflection in galvanometer**
iii.	$I_B < I_E$. **This happens when VPA < E. Other side defection in galvanometer**

⇒ Note that the temperature of potentiometer wire must be remains constant and it will be uniform must.

⇒ it works on the principle. "if a wire of uniform area of cross section is carrying a steady current then fall of potential across any portion of the wire is directly proportional to the length of that portion".

$$V \propto l \Rightarrow V = Kl$$

⇒ $K = V/l$ is potential gradient which is fall of potential per unit length.

⇒ *unit of potential gradient is* Vm^{-1} *or* Vcm^{-1}.

⇒ *Ratio of emf with length is given by;*

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

- **Note**: greater the length of potentiometer wires the greater is the sensitivity of potentiometer.

⇒ ***The potential difference V across R can be measured as;***

$$V = \left(\frac{E}{R+r}\right)\frac{r}{L}l$$

⇒ ***To find the internal resistance by potentiometer; (This is to just give idea, not in course)***

$$r = \left(\frac{l_1 - l_2}{l_2}\right)R$$

⇒ ***Sensitivity of potentiometer;***

A sensitive galvanometer can measure the smallest potential difference between any two points.

1) The sensitivity of galvanometer can be increased by decreasing potential gradient.
2) The sensitivity can be also increased by increasing length of potentiometer.
3) It can also increase by inducing current in galvanometer wire with a resistance in series with potentiometer wire.

⇒ **Voltmeter is a device that is also used to measure potential difference than what is the difference between voltmeter and potentiometer?**

It is because;

1) It is a null deflection method therefore we can find balanced condition with high accuracy.
2) During measurement through potentiometer no current pass through potentiometer itself therefore it gives us accurate measurement.
3) Note that potentiometer is a voltmeter with infinite resistance so it is an ideal voltmeter.
4) The scale can be made long for maximum accuracy.

If sometimes balanced point is not obtained on potentiometer wire then it is because the potential difference across measurement is greater than the potential drop across the potentiometer wire. So, for this case we should use a battery source of large emf.

Important points

⇒ At null point since no current flows through E therefore it is said to be in the condition of open circuit.

⇒ More is the length of potentiometer, higher is the sensitivity of potentiometer and smaller is the potential gradient.

⇒ Potentiometer will work only when B > E. Also the positive terminal of the batteries is connected at P. If any of the above conditions is not llowed, we do not get a null point.

FORMULAS SHEET

1.	Electric current	$I = \frac{\Delta q}{\Delta t}$		
2.	Heat produced in a conductor	$H = I^2Rt$		
3.	Ohm's law	$I = (\frac{1}{R})V$	$V = IR$	
4.	Resistance	$R = \frac{V}{I}$	$R = \rho\frac{L}{A}$	$R = \frac{1}{G}$
5.	Parallel combination of resistance	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$		
6.	Parallel combination of resistance	$R_{eq} = R_1 + R_2 + R_3$		
7.	Conductance	$G = \frac{1}{R}$	$G = \rho\frac{A}{L}$	
8.	Resistivity	$\rho = \frac{RA}{L}$	$\rho = \frac{1}{\sigma}$	
9.	Conductivity	$\sigma = \frac{1}{\rho}$		
10.	Temperature co-efficient of resistance	$\alpha = \frac{R_t - R_o}{R_o t}$		
11.	Temperature coefficient of resistivity	$\alpha = \frac{\rho_t - \rho_o}{\rho_o t}$		
12.	Electrical power of batter	$P = \frac{\Delta W}{t}$	$P = V\frac{\Delta q}{\Delta t}$	$P = VI$
13.	Electrical power dissipated in resistor	$P = VI$	$P = I^2R$	$P = \frac{V^2}{R}$
14.	Emf of battery	$E = \frac{\Delta W}{\Delta q}$		
15.	Relation between emf and V	$E = IR + Ir$	$E = V_t + Ir$	$V_t = E - Ir$
16.	Maximum power output of the battery	$P_{max} = \frac{E^2}{4r}$		
17.	Kirchhoff's current rule	$\sum I = 0$		
18.	Kirchhoff's current rule	$\sum V = 0$		
19.	Wheatstone bridge	$\frac{R_1}{R_2} = \frac{R_3}{R_4}$	$R_1R_4 = R_2R_3$	
20.	Emf of the cell	$E_x = \frac{l}{L}E$		

UNITS

1.	Electric current	Ampere	C/s
2.	charge	Coloumb	As
3.	Resistance	Ω	V/A
4.	Resistivity	Ωm	
5.	Conductance	Ω^{-1}	mho, siemen
6.	Conductivity	$\Omega^{-1}m^{-1}$	mho m^{-1}
7.	Temperature co-efficient of R	K^{-1}	
8.	Electrical power	J/s	Watt
9.	Emf	J/C	Volt

Chapter No: 12 "Current Electricity"

Some important Points & tricks

1) The resistance depends on the arrangements of atoms in the material i.e. on the kind of material (copper, silver etc.).
2) Wait and kilowatt are the units of electrical power and watt hour and kilowatt hour are the units of electrical energy.
3) For a given conductor, current does not change with change in cross-sectional area.
4) Alternating current shows heating effect only, while direct current shows heating effect, chemical effect and magnetic effect.
5) Greater the electric field, larger will be the drift velocity.
6) Resistivity is the intrinsic property of the substance. It is independent of shape and size of the body.
7) The device which converts chemical energy into electrical energy is known as electric cell. It is a source of constant emf But not of constant current.
8) Kirchhoff's first law and second law represent conservation of charge and energy respectively.
9) Wheatstone bridge is most sensitive if all the arms of bridge have equal resistances i.e., P = Q = R = S.
10) The relation V = 1R holds good for both ohmic and non-ohmic conductors. For ohmic conductors, R is constant and for non-ohmic conductors, R is not constant for different values of V and 1 (thus the graph of V against 1 is not a straight line).
11) Electric current has direction as well as magnitude but it is not a vector quantity because current does not add like vectors.
12) The electrons drift in the direction of increasing potential i.e., drift velocity of conduction electrons is opposite to the direction of electric field.
13) Resistance of a material depends on its geometrical dimensions (length, cross sectional area) and nature of material of the conductor.
14) The electromotive force e.m.f is the maximum potential difference between the two electrodes of the cell when no current is drawn from the cell.
15) In Wheatstone bridge, it is not possible to measure very low1 and very high resistances.
16) In a potentiometer, the potential at point A (of wire AB) is higher than the potential at lip of jockey and B is at lower potential than that at the tip of jockey.
17) In potentiometer, current will flow from point A (of wire AB) into the jockey tip and from jockey? tip into point B.
18) The working of potentiometer is based on null deflection method.
19) The difference between e.m.f and terminal voltage is called lost voltage which is not indicated by voltmeter.
20) In series resistance circuit, current through each resistor is the same.
21) In parallel resistance circuit, potential difference across each resistor is the same and is equal to the applied potential difference.
22) The conductors behave as superconductors at very low temperatures. When current is drawn from a cell i.e., during discharging; V < E and during charging of cell; V > E, where V is terminal potential difference and E is e.m.f of cell.
23) In Wheatstone bridge, when current through galvanometer is zero, the potential difference between B and D is zero.
24) If diameter d of a conductor is doubled (or increased), then drift velocity of electrons inside it will not change.
25) After stretching, if length of a conductor increases by x%, then resistance increases by 2x% (valid only if< 10%).
26) For a conducting wire having resistance R, keeping its mass constant,
    i. if it its length is increased n times, then R changes to n^2R
    ii. if its radius increases n times, then R changes to $\frac{R}{n^4}$
    iii. if its cross-sectional areas increases n times, then R changes to $\frac{R}{n^2}$.
27) Using n conductors of equal resistance, the number of possible combinations is 2^{n-1}.
28) If the resistances of n conductors are totally different, then the number of possible combinations will be 2^n.

29) If n identical resistances are first connected in series and then in parallel, the ratio of the equivalent resistance is given by $\frac{R_P}{R_S} = \frac{n^2}{1}$.

30) If a wire of resistance R is cut in n equal parts and then these parts are collected to form a bundle then equivalent resistance of the combination will be $\frac{R}{n^2}$.

31) The reciprocal of slope of V - I graph gives the resistance.

32) If three identical resistors, each of resistance R are connected in the form of a triangle, the equivalent resistance between the ends of a side is equal to (2R/3).

33) If four identical resistors, each of resistance R are connected in the form of a square, the effective resistance between ends of a diagonal is R.

34) For the questions in which different types of circuits for the combinations of resistances are given, first reduce the circuit by knowing the common or junction points and try to arrange them in series. Solve the inner combinations or parallel combinations in different branches where reduction is not possible easily.